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EFFECTS OF A COMMERCIAL DRINK ON ACCELERATION TOLERANCE AND COGNITIVE PERFORMANCE

Thomas B. Walker
711 HPW/RHPF
Air Force Human Resources Laboratory
Brooks City-Base, TX 78235

Ulf Balldin
Wyle Laboratories, Inc.
Wyle Integrated Sciences and Engineering Group
1290 Hercules Drive
Houston, TX 77058

Joseph Fischer
General Dynamics, Inc.
Advanced Information Services
5200 Springfield Place
Dayton, OH 45431

William Storm
Wyle Laboratories, Inc.
Wyle Integrated Sciences and Engineering Group
1290 Hercules Drive
Houston, TX 77058

Gordon L. Warren
Division of Physical Therapy
School of Health Professions
Georgia State University

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Air Force Research Laboratory
711 Human Performance Wing
Human Effectiveness Directorate
Biosciences and Performance Division
Biobehavior, Bioassessment & Biosurveillance Branch
Brooks City-Base, TX 78235

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WAYNE ISDAHL	MARK M. HOFFMAN
Work Unit Monitor	Deputy Division Chief
Biobehavior, Bioassessment &	Biosciences and Performance Division
Biosurveillance Branch	Human Effectiveness Directorate
	711 Human Performance Wing
	Air Force Research Laboratory

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Walker, T.B.*, Balldin, U.[⌂], Fischer, J.[Δ], Storm, W.[⌂] and Warren, G.[√]

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*Air Force Materiel Command
Air Force Research Laboratory
711 Human Performance Wing
Human Effectiveness Directorate
Biosciences and Performance Division
Biobehavior, Bioassessment, and
Biosurveillance Branch
Brooks City-Base, TX 78235

[⌂]Wyle Laboratories, Inc.
Life Sciences Group
1290 Hercules Drive
Houston, Texas 77058

[Δ]General Dynamics
Advanced Information Services
5200 Springfield Place
Dayton, Ohio 45431

[√]Georgia State University
PO Box 3965
Atlanta, GA 30302

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Biosurveillance Branch
2485 Gillingham Dr
Brooks City-Base, TX 78235

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14. ABSTRACT.
This study examined the ability of a commercial energy drink to enhance acceleration tolerance, strength under G-load, and cognitive performance immediately prior to and following acceleration exposure. Eight experienced centrifuge subjects completed three separate experimental acceleration exposures following ingestion of 11.5 ml/kg body weight of a) a caffeine-carbohydrate drink, providing 5.0 mg caffeine/kg body weight, b) a carbohydrate-only drink or c) placebo. Each exposure consisted of a relaxed gradual onset run to peripheral light loss, a rapid onset run to 6.0 G for 15 s, and a simulated air combat maneuver (SACM) run of repeated alternations between 4.5 G for 15 seconds and 7G for 15 seconds until volitional exhaustion. Cognitive tests were performed prior to and after the acceleration profiles. Relaxed G-tolerance was significantly higher under the caffeine session, whereas SACM duration did not differ among the drink conditions. Hip adductor muscle strength was lower during the placebo session than during the other two sessions. Cognitive reaction time was faster post-acceleration than pre-acceleration, and faster under the caffeine condition than the placebo condition. We conclude that consumption of a caffeine-based energy drink enhances relaxed G-tolerance and may increase strength, but does not impact acceleration duration. We further conclude that cognitive reaction time is improved by the caffeine drink, as well as by the acceleration exposure.

15. SUBJECT TERMS Acceleration tolerance, cognitive performance, G-tolerance

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NOTE: Nothing in this report is intended to state or imply official Air Force or U.S. Government approval, recommendation or endorsement of the Coca Cola Company or the product tested.

Executive Summary

Purpose:

The primary objective of this study was to investigate the ability of a commercially-available energy drink containing caffeine to improve anti-G straining performance during repetitive high-G simulated flight maneuvers. A secondary objective was to explore the influence of caffeine and acceleration forces on cognitive performance.

Methods:

Ten experienced centrifuge riders attempted three +Gz centrifuge exposures: a 0.1 G/s onset exposure while relaxed until 100% of peripheral vision was lost, a 6.0 G/s onset run, with anti-G straining maneuver (AGSM) performed, to 6.0 Gs for 15 s, and a "simulated aerial combat maneuver" (SACM) with AGSM that consisted of alternating 10 s exposures to 4.5 and 7.0 Gs. Subjects did not wear G-protective suits during these exposures. Subjects underwent these exposures after ingesting, in separate trials, either a commercially-available caffeinated energy drink (Full Throttle®, made by the Coca-Cola Company, at volumes equating to a caffeine dose of 5 mg caffeine per kg of body weight), an uncaffeinated version of the energy drink, or a flavored water (hydration placebo control) via a randomized double-blind research design. Immediately prior to and following G exposure, subjects completed two cognitive tests, an alertness survey, and a mood questionnaire. Parameters measured included relaxed G-tolerance, blood pressure, strength, SACM endurance, cognitive performance, mood state, and alertness.

Results and Conclusions:

Eight of the ten subjects were considered to have valid data for analysis. Relaxed gradual onset G-tolerance was significantly higher during the caffeinated drink condition than during the other two treatment conditions. There were no significant differences between treatments for SACM duration. Hip adductor strength under G was lower during the placebo session than during the other two sessions.

Math Processing Reaction Time was significantly faster under the caffeine condition than under the no caffeine and placebo conditions, and a similar, but marginally significant trend was seen for Continuous Processing Reaction Time. Reaction time for both cognitive measures was faster after the centrifuge ride than before the ride regardless of which drink was consumed.

We conclude that moderately large doses of a caffeine-based energy drink prior to acceleration exposure appear to have a positive effect on relaxed G-tolerance, but do not improve (nor impair) the duration (ride time) of simulated aerial combat maneuvers. Both caffeine and physical exertion enhanced cognitive processing speed.

INTRODUCTION

Objective

The primary objective of this study was to investigate the ability of a commercially-available energy drink containing caffeine to improve anti-G straining performance during repetitive high-G simulated flight maneuvers. A secondary objective was to explore the influence of caffeine and acceleration forces on cognitive performance.

Background

Advanced fighter aircraft are capable of operating in high-G environments and are often limited by the physiological capabilities of the aircrew. Aircrew members must perform an anti-G straining maneuver (AGSM) just prior to and during a high-G aircraft maneuver to prevent G-induced loss of consciousness (GLOC). The inability to maintain and repeatedly perform an AGSM can result in the loss of life and aircraft. Millions of dollars have been spent on the development of life support equipment to help prevent GLOC. Ergogenic aids containing caffeine, such as energy drinks, are readily available and may prove to enhance performance of the AGSM during high G via reduction of muscle fatigue associated with repeated isometric contractions. Recent studies have demonstrated that relatively low doses of caffeine are effective in improving exercise performance and muscular strength and endurance (Cureton et al., 2007; James et al., 2005; Kalmar, 2005; Meyers & Cafarelli, 2005; Pasman et al., 1995; Plaskett & Cafarelli, 2001) making caffeine a potentially valuable aid in the high-G combat environment. While one study (Florence et al., 1991) of rhesus monkeys failed to show any effect of caffeine on cardiovascular complications or relaxed G tolerance (without performing AGSM), the efficacy of caffeine in humans to aid an active anti-G straining maneuver has not been investigated. This study was conducted to evaluate the ability of a caffeinated energy drink to serve as an inexpensive yet effective aid by enhancing the performance of anti-G straining maneuvers in a high-G environment. The study also provided a propitious opportunity to evaluate the effects of caffeine, acceleration forces, and physical exertion on cognitive performance.

METHODS

Participants

Ten volunteer subjects, including two females, were recruited from the Brooks City-Base human centrifuge subject panel (active duty military only). Centrifuge panel members are pre-screened for appropriate health and fitness clearances. Panel members must complete introductory training on the centrifuge and demonstrate the capability to tolerate exposures up to +9 Gz when wearing standard G-protection ensembles. From a medical standpoint, potential panel members

are included or excluded through a physical examination based on USAF Flying Class II/III standards which screen for any medical issues precluding centrifuge exposure. By virtue of being voluntary members of the centrifuge panel, the subjects receive military incentive pay ($150 per month) for their voluntary exposure to acceleration stress. The research protocol for this study was reviewed and approved by the AFRL Institutional Review Board prior to subject recruitment and the subjects gave written informed consent before participating. Female subjects provided a negative pregnancy test within 72 hours prior to each of their centrifuge exposures.

Facilities

The 711 Human Performance Wing (HPW) human-rated centrifuge is engineered to generate acceleration forces similar to those encountered during flight and air combat maneuvering. It is comprised of a power head, rotational arm, gondola, and equipment fixture. The rotating arm produces centrifugal force and the free swinging action of the gondola orients the human subject such that the resultant G vector is aligned with the subject's z-axis producing +Gz (so that blood is forced from head to feet). Cognitive testing was conducted in an environmentally comfortable but isolated, sound-attenuating chamber.

Experimental Design

This study employed a repeated measures design and double-blind procedures. Each subject participated in three dosing conditions, each condition randomly assigned to one of three experimental sessions. The conditions consisted of ingesting (1) a commercially-available caffeinated energy drink (Full Throttle®, produced by the Coca-Cola Company, containing 9.0 mg caffeine per 1 oz fluid), (2) a modified version of the energy drink comprised of the same ingredients but for the removal of caffeine and guarana, or (3) a placebo version of the drink with all of the 'energy' ingredients removed (i.e., no HFCS, B-vitamins, ginseng, guarana, L-carnitine, or taurine). In this paper the three dose conditions will be respectively referred to as caffeine, non-caffeine, and placebo. All drinks were prepared by the Coca-Cola Company and administered to the subjects in sealed bottles which had coded labels so as to obscure each drink's composition.

Procedures

Dosing and Testing Schedules. The three experimental sessions were conducted at approximately the same time of day for each subject, with at least 64 hours lapsing between sessions to allow for recovery. Subjects were instructed to abstain from caffeine consumption for 14 hours, and from food and tobacco consumption for six hours, before each session. Dosing

was based on each subject's weight, and, for each experimental session, administered in two drinking portions. In each experimental condition, the first drink consisted of 10.95 ml of drink per kg body weight; the second 5.48 ml of drink per kg body weight. For the caffeine trial this volume resulted in a caffeine dose of 5.0 mg caffeine per kg of body weight. The first drink was issued to the subject 1-3 days prior to the day of each experimental session for self-administration by the subject prior to reporting to the centrifuge facility. Subjects were instructed to keep the drink refrigerated until ingesting it 2.5 hours prior to the scheduled centrifuge run. Subjects ingested the second drink immediately on arriving at the centrifuge facility 30-45 minutes prior to the centrifuge run. Each drink was consumed within two minutes. After ingesting the second drink, the subject was given a brief medical examination and instrumented with electrocardiograph (ECG) monitoring leads as required for centrifuge exposure. The subject then completed a 10-minute cognitive testing battery. Immediately on completion of cognitive testing, he/she was emplaced in the centrifuge gondola for acceleration testing which required 15-30 minutes depending on the subject's G-tolerance. On completion of acceleration testing an 8 ml sample of venous blood was drawn from the subject for subsequent assay of serum caffeine, glucose and lactate. He/she then again completed the cognitive test battery, was debriefed, and departed the facility.

Acceleration Profiles and G-Tolerance Measures. For this study an F-16 seat (30-degree back tilt) was installed in the centrifuge gondola and subjects did not wear an anti-G suit. Subjects were sequentially exposed to the same three acceleration profiles during each experimental session. Baseline heart rate and blood pressure data were collected prior to conducting the acceleration profiles.

Gradual Onset Profile. Subjects were first exposed to a profile consisting of 0.1 G/s onset rate to a maximum of +9Gz while maintaining a relaxed state (i.e., no AGSM) to the point of 100% loss of peripheral vision or 50% loss of central vision.[1] The outcome measures were maximum G-level attained and mean blood pressure and heart rate measured at a "common G-level" during the centrifuge run. A "common G-level" is defined as the lowest maximum G-level attained by a subject across the three experimental sessions, and was determined for each subject, individually. It was necessary to measure blood pressure and heart rate at a common G-level to avoid bias when comparing the three drink conditions. For example, if a subject went to +6Gz under one drink, and +9Gz under another drink, his/her blood pressures and/or heart rates might differ simply due to the additional stress of the higher G, not because of a difference caused by the drinks.

[1] Losses of central and/or peripheral vision are useful subjective measures of G tolerance. In the centrifuge gondola a single central red light and two peripheral green lights are mounted on a horizontal bar 30 inches in front of the seated subject. The central light is directly on the subject's horizontal centerline of sight and the two peripheral lights are each at a 25° angle on either side of the central light. Loss of vision to the lights may be used as a pre-defined end point to terminate G exposure (usually 100% loss of peripheral vision or 50% loss of central vision), or reported at the termination of an exposure as a per cent loss experienced (e.g., 20% loss peripherally; 0% centrally).

Rapid Onset Profile. This profile employed an onset rate of 6 G/s to +6Gz for a duration of 15 seconds during which the subject did perform AGSM. Outcome measures were the duration of time at 6 G, mean heart rate and blood pressure (measured at a common point in time, as per the argument presented in the above paragraph), percent of central and peripheral light loss, and estimated subjective maximum effort required to perform AGSM.

Simulated Aerial Combat Maneuver (SACM). This profile consisted of up to 15 repeated alternations between +4.5Gz for 15 seconds and +7Gz for 15 seconds during which the subject performed AGSM as needed until the subject self terminated due to fatigue, light loss, or completion of 15 alternations. During the first 5 seconds of each +7Gz exposure the subjects performed a maximum voluntary isometric contraction (MVIC) of their hip adductor muscles as part of their AGSM. Outcome measures were duration of time at G, mean heart rate and blood pressure (measured at a common point in time), light loss, and subjective effort. MVIC strength was measured by a padded force transducer located between the subject's knees. Arterial blood pressure was recorded during all the G-exposures by a non-invasive photo-plethysmographic technique (Portapres®, TNO, Delft, The Netherlands) with a pressure cuff around the mid-phalanx of the third finger on the left hand. The forearm and hand were supported by a sling and the hand positioned at heart level and enclosed in a pre-heated glove to avoid vasoconstriction of the finger blood vessels by a cool environment.

Cognitive Testing and Subjective Measures. Three instruments from the *Automated Neuropsychological Assessment Metrics* (ANAM; Reeves, Winter, Kane, Elsmore, & Bleiberg, 2001) battery and one additional paper-and-pencil survey, the *Profile of Mood States* (POMS; McNair, Lorr, & Droppleman, 1971) were selected to assess subject alertness, cognitive capability, and affective state immediately before and after each subject's centrifuge exposure. Each cognitive test session required about 10 minutes for the well-trained subjects to complete, always in the following sequence.

Alertness. The ANAM battery offers an automated version of the Stanford Sleepiness Scale that maintains the original seven-point scale, rating subjective sleepiness from "*1-very alert, wide awake, and energetic*" to "*7-very sleepy and cannot stay awake much longer*." The subject simply entered the number of the statement best describing his/her status at the time.

Cognition. The Mathematical Processing Task (MPT) and Continuous Processing Task (CPT) were selected from the ANAM battery to assess cognitive performance. The outcome measures of percent correct responses (accuracy), and mean reaction time for correct responses were generated for both tasks. Each MPT problem includes two mathematical operations (addition and/or subtraction) on sets of three single-digit numbers (e.g., 5+3–4=?). The subject is instructed to read and calculate from left to right and indicate whether the answer is greater-than or less-than '5' by pressing the left or right response buttons on the mouse. Trials were subject-paced and three minutes in duration. The CPT required subjects to continuously monitor a randomized sequence of the numerals 0 through 9 presented one at a time, one per second, in the center of the screen. Subjects pressed the left mouse key if the numeral currently on the

screen matched the numeral that immediately preceded it and the right mouse key if there was not a match. Trials were subject-paced and three minutes in duration.

Affect. Subjective evaluations of mood were acquired using the POMS. This survey consists of 65 adjectives describing feeling and mood to which the client responds according to a five-point scale ranging from "Not at all" to "Extremely." Subjects were instructed to indicate mood status for "how you feel right now" with regards to each item. A standardized "state" measure is generated for each of six mood categories; anger, confusion, depression, fatigue, tension, and vigor. Completion of the POMS required about three minutes.

Statistical Analyses

For the majority of the centrifuge outcome variables, a repeated measures analysis of variance (ANOVA) with one factor was performed to test for differences among the three drink conditions. When a significant drink effect was found, post-hoc analyses (paired t-tests) were used to identify specific differences among the three drinks. Because of the non-normality of the Central Light Loss, Peripheral Light Loss, and Arrhythmia measures, non parametric tests (Friedman's Test and Wilcoxon Signed Rank Test) were used in place of the ANOVAs and t-tests to test for differences among the drink conditions. For each cognitive and mood outcome variable, a repeated measures ANOVA with two factors was performed to test for drink main effects, pre- versus post-acceleration main effects (hereafter referred to as 'acceleration' main effect), and drink-by-acceleration interaction. When the drink main effect test or the drink-by-acceleration interaction test was significant appropriate post-hoc tests (i.e., paired t-tests) were performed to identify specific differences among the drinks. For all ANOVAs (and Friedman's Tests), alpha=0.05 was used as the level for statistical significance. To aid with interpretation and to identify trends, the level of significance was relaxed to alpha= 0.10 for all post-hoc tests.

RESULTS

Missing Data

Ten subjects were utilized in this study. However, one subject had trouble completing the centrifuge rides (GLOC on two of the rapid onset rides and a near GLOC on the third, and GLOC on two of the three SACM rides). This subject is a relatively experienced rider who usually performs satisfactorily when wearing a G-suit. For this study the subjects were not wearing G-protection, and it was determined that the G-levels used were slightly too high for this individual's unprotected innate G tolerance. Consequently, this subject's data were not included in any of the analyses. Another subject, upon post-study analysis of the serum data, was found to have significant serum caffeine levels (>5µM) during all three of the experimental conditions, suggesting that the subject did not abstain from caffeine as directed by the protocol. This

subject's data were also deleted from all analyses. In addition, due to technical problems, blood pressure data was not always available for all centrifuge runs of each subject. Thus, for each blood pressure outcome measure, only subjects with data for all three conditions were included in the analysis.

Acceleration Tolerance

Table 1 summarizes the means and standard deviations for each of 25 centrifuge variables, and shows the ANOVA and post-hoc test results for each. Most of the variables are of secondary interest, but for completeness have been included in this report.

The variable of primary interest for this study was the duration of the SACM ride. The observed averages were about 30s higher for the caffeine and placebo drinks compared to the no caffeine drink, but these differences were not statistically significant. Another variable of high interest in this study was Relaxed Gradual Onset G-Tolerance. G-Tolerance was significantly higher under the caffeine condition than under the no caffeine and placebo conditions by 0.9 and 0.7 +Gz, respectively. Finally, a third variable of interest was MVIC (measured at a common G-level). The caffeine and no caffeine conditions produced MVIC means that were significantly higher than the placebo mean by 29% and 32%, respectively.

Significant drink effects were found for two centrifuge variables of secondary interest: Rapid Onset Peripheral Light Loss and SACM Peripheral Light Loss. In both cases, the percentage of subjects experiencing any degree of light loss appeared higher in the no caffeine condition than in the other two conditions, but the only significant difference was between the no caffeine mean and the placebo mean.

Cognitive Performance, Mood States, and Alertness

Table 2 presents the means and standard deviations for each of the cognitive performance outcome measures, and summarizes the ANOVA and post-hoc test results for both cognitive tasks. No significant drink-by-acceleration interactions were found for any of the performance outcome measures, therefore post-hoc tests were limited to those cases where significant drink and acceleration main effects were found.

For the Math Processing Task, there was no statistical evidence that the accuracy of the subjects' responses was affected by either acceleration or the drink conditions. Overall-reaction-time, on the other hand, was significantly faster after the acceleration exposure than before, regardless of which drink was consumed (i.e., a significant acceleration main effect). There was also a significant drink main effect for which post-hoc tests revealed that average overall-reaction-time

was significantly faster under the caffeine condition than under the no caffeine and placebo conditions by 157 and 209 msec, respectively (i.e., approximately 10% and 13% faster, respectively).

For the Continuous Processing Task, there was no statistical evidence that the accuracy of the subjects' responses was affected by either acceleration or drink condition. However, overall-mean-reaction-time exhibited a significant acceleration main effect (overall post-acceleration reaction time was faster than overall pre-acceleration reaction time). The test for drink main effects was also significant. Post-hoc testing indicated that, while average overall-reaction-times were faster under the caffeine and no-caffeine conditions than under the placebo condition, the differences were only marginally significant ($p = .055$ and $p = .088$, respectively).

Findings for the six POMS mood states and subjective alertness ratings on the Stanford Sleepiness Scale are summarized in Table 3. Three of the Mood variables showed significant changes from pre- to post-acceleration: confusion increased, fatigue increased, and vigor decreased. There was no statistical evidence that any of the mood states were affected differentially by the three drink conditions, although there was a trend ($p = .066$) for tension to be higher under the caffeine condition than under the other two conditions. The difference between overall-mean-alertness-ratings reported on the Stanford Sleepiness Scale before and after acceleration exposure approached significance ($p = .066$), with participants being more alert prior to acceleration. No differences due to drink condition were found among the Stanford scores.

Table 1. Acceleration Data: Means, Standard Deviations, and Statistical Test Results.

G-Profile	Variable	Drink Condition*			ANOVA Results			t-test Results
		Caffeine	No-Caffeine	Placebo	MSE	F(n, d)	p	
Resting	SBP (mmHg) [n=6]	146 8	129 23	138 17	284.2	1.54 (2,10)	0.262	
	DBP (mmHg) [n=6]	74 11	63 15	72 13	46.5	3.92 (2,10)	0.055	
	HR (bpm) [n=8]	63 12	67 21	64 15	167.9	0.23 (2,14)	0.797	
Relaxed Gradual Onset Run	G-level Attained [n=8]	6.9 1.6	6.0 1.2	6.2 1.5	0.183	9.69 (2,14)	**0.002**	No-caff<caff (p=.004) pla<caff (p=.017)
	SBP (mmHg) [n=5]	214 36	209 40	177 59	933.4	2.19 (2,8)	0.174	
	DBP (mmHg) [n=5]	124 17	114 13	110 30	191.6	1.35 (2,8)	0.313	
	HR (bpm) [n=8]	96 11	99 14	91 19	82.8	1.42 (2,14)	0.276	
Rapid Onset Run (with AGSM)	Duration (sec at 6 G) [n=8]	15 0	14 2	15 0	1.50	1.5 (2,14)	0.393	
	SBP (mmHg) [n=4]	237 23	203 43	256 18	1056.5	2.76 (2,6)	0.141	
	DBP (mmHg) [n=4]	138 20	124 36	152 25	332.6	2.23 (2,6)	0.188	
	HR (bpm) [n=8]	139 18	134 21	132 20	34.9	2.52 (2,14)	0.117	
	% Subjects With Any Central Light Loss [n=8]	13%	38%	0%	Friedman's Test Chi sq (2)=5.60		0.061	
	% Subjects With Any Peripheral Light Loss [n=8]	25%	63%	13%	Friedman's Test Chi sq (2)=6.12		**0.047**	No-caff>pla (**p=.039**) (Wilcoxon Test)
	Subjective Effort (0-11 score) [n=7]	6.4 1.4	6.4 2.1	6.3 2.4	0.7 14	.067 (2,12)	0.936	

***** Mean values are the upper number in each cell; standard deviations are the lower number in each cell.

(table continued on next page)

Table 1. *(continued)*

G-Profile	Variable	Drink Condition*			ANOVA Results			t-test Results
		Caffeine	No-Caffeine	Placebo	MSE	F(n, d)	p	
Simulated Air Combat Maneuver (with AGSM)	Duration (seconds) [n=8]	206 131	173 92	204 102	1204.1	2.29 (2,14)	0.138	
	SBP (mmHg) [n=5]	252 55	264 31	243 67	411.6	1.43 (2,8)	0.295	
	DBP (mmHg) [n=5]	153 21	132 21	137 28	448.8	1.37 (2,8)	0.309	
	HR (bpm) [n=8]	151 20	148 23	146 23	82.8	1.42 (2,14)	0.276	
	% Subjects With Any Central Light Loss[n=8]	38%	63%	0%	Friedman's Test Chi sq (2)=5.47		0.065	
	% Subjects With Any Peripheral Light Loss [n=8]	38%	75%	25%	Friedman's Test Chi sq (2)=6.00		**0.050**	No-caff>pla (**p=.042**) (Wilcoxon Test)
	Subjective Effort (0-11 score) [n=8]	9.0 1.7	9.1 1.6	7.9 2.1	1.36	2.78 (2,14)	0.096	
	MVIC max [n=8]	88 23	87 17	94 24	162.8	0.68 (2,14)	0.525	
	MVIC at Common G [n=8]	76 23	78 28	59 26	225.2	3.96 (2,14)	**0.043**	pla<no-caff (**p=.043**) pla<caff (**p=.043**)
Arrhythmias	% subjects with PVC's[n=8]	75%	38%	50%	Friedman's Test Chi sq (2)=3.60		0.165	
	% subjects with other arrhyt. [n=8]	13%	0%	0%	Friedman's Test Chi sq (2)=2.00		0.368	

***** Mean values are the upper number in each cell; standard deviations are the lower number in each cell.

Table 2. Cognitive Test Scores Summary Data and Statistical Test Results

Test	Variable	Accel-eration	Drink Condition*					ANOVA Results				t-tests Comparing Overall Drink Means
			Caffeine	No-Caffeine	Placebo	Overall			Accel-eration	Drink	Accel-eration by Drink	
CPT	Accuracy (%)	Pre	98.1 1.3	97.0 1.9	97.0 1.1	97.4 1.1		MSE df F p	0.752 1,7 .28 .612	0.799 2,14 3.55 .057	1.901 2,14 .49 .624	
		Post	97.5 1.3	97.3 1.3	96.9 1.6	97.2 1.1						
		Overall	97.8 1.0	97.2 1.3	97.0 1.1							
	Mean Reaction Time (msec)	Pre	442 118	450 94	491 130	461 111		MSE df F p	820 1,7 10.75 **.014**	1596 2,14 3.97 **.043**	646 2,14 1.13 .351	caff<pla (p=.055) no-caff<pla (p=.088)
		Post	421 94	432 94	449 106	434 96						
		Overall	432 106	441 94	470 116							
MPT	Accuracy (%)	Pre	95.4 6.9	93.1 5.8	94.5 3.4	94.3 4.9		MSE df F p	20.86 1,7 .92 .370	9.29 2,14 .08 .924	4.47 2,14 3.62 .054	
		Post	94.6 4.8	96.4 4.0	95.7 3.7	95.6 3.8						
		Overall	95.0 5.3	94.7 4.4	95.1 3.0							
	Mean Reaction Time (msec)	Pre	1466 455	1687 553	1688 490	1614 484		MSE df F p	13997 1,7 13.53 **.008**	34248 2,14 5.53 **.017**	9500 2,14 1.85 .194	caff<no-caff (p=**.022**) caff<pla (p=.**030**)
		Post	1391 374	1486 475	1587 495	1488 437						
		Overall	1429 410	1586 509	1638 488							

***** Mean values are the upper number in each cell; standard deviations are the lower number in each cell.

Table 3. Mood State Scores and Alertness Ratings Summary Data and Statistical Test Results.

Test	Variable	Accel-eration	Drink Condition*					ANOVA Results**			
			Caffeine	No-Caffeine	Placebo	Overall			Accel-eration	Drink	Acceleration by Drink
POMS	Anger (scale range: 37 – 80)	Pre	37.9 1.6	38.3 1.5	38.4 1.5	38.2 1.3		MSE df F p	8.61 1,7 .09 .776	4.42 2,14 .20 .819	2.47 2,14 .48 .629
		Post	38.4 3.9	38.9 5.3	38.0 1.4	38.4 3.4					
		Overall	38.1 2.6	38.6 3.2	38.2 1.4						
	Confusion (scale range: 30 – 80)	Pre	34.5 3.6	35.3 4.8	33.6 3.2	34.5 3.1		MSE df F p	16.21 1,7 8.43 **.023**	9.13 2,14 .06 .938	6.77 2,14 1.44 .270
		Post	37.4 5.4	37.4 4.6	38.8 4.6	37.8 4.4					
		Overall	35.9 3.4	36.3 4.6	36.2 3.4						
	Depression (scale range: 37 – 80)	Pre	37.1 .4	37.3 .5	37.6 1.4	37.3 .5		MSE df F p	1.71 1,7 .11 .750	.896 2,14 .44 .652	.479 2,14 2.74 .099
		Post	37.4 .7	37.9 1.6	37.1 .4	37.5 .8					
		Overall	37.3 .5	37.6 .9	37.4 .7						
	Fatigue (scale range: 34 – 77)	Pre	36.4 2.9	37.1 2.6	36.5 3.3	36.7 2.6		MSE df F p	68.67 1,7 7.77 **.027**	9.31 2,14 .087 .917	6.18 2,14 .934 .416
		Post	44.1 10.3	42.5 6.3	43.4 6.6	43.3 7.4					
		Overall	40.3 8.0	39.8 4.0	39.9 4.1						
	Tension (scale range: 31 – 80)	Pre	39.3 6.4	37.4 3.0	35.9 3.8	37.5 3.5		MSE df F p	42.48 1,7 .79 .405	16.59 2,14 3.32 .066	12.18 2,14 .156 .857
		Post	40.9 10.5	39.8 6.9	36.9 5.2	39.2 7.2					
		Overall	40.1 7.5	38.6 4.7	36.4 3.6						
	Vigor (scale range: 30 – 76)	Pre	51.6 15.5	47.5 11.9	49.0 14.3	49.4 13.3		MSE df F p	25.85 1,7 10.48 **.014**	25.55 2,14 2.03 .168	12.60 2,14 1.23 .323
		Post	46.5 13.3	44.9 13.9	42.5 13.9	44.6 13.4					
		Overall	49.1 14.0	46.2 12.7	45.8 13.9						
Alertness Scale	Score (scale range: 1 - 7)	Pre	1.8 .9	1.9 .8	1.9 1.0	1.8 .7		MSE df F p	.845 1,7 4.83 .064	.658 2,14 .10 .910	.426 2,14 .049 .952
		Post	2.4 1.3	2.4 1.1	2.5 .8	2.4 .9					
		Overall	2.1 1.0	2.1 .9	2.2 .6						

* Mean values are the upper number in each cell; standard deviations are the lower number in each cell.

** **Since** no significant drink or drink-by-acceleration effects were detected, post-hoc t-tests were not performed

DISCUSSION

The primary finding of this investigation was that ingestion of a caffeine-based energy drink, delivering 5.0 mg of caffeine per kg body weight, did not significantly influence acceleration endurance for subjects while performing the AGSM during rapid onset or SACM exposures. However, caffeine ingestion did result in a significant improvement in relaxed gradual onset G-tolerance, and appeared to increase hip adductor strength levels measured during the performance of the AGSM. Caffeine ingestion and physical exertion also resulted in faster reaction times on the two cognitive processing tasks.

Acceleration Tolerance. An effective AGSM can improve G-tolerance by over 3 $+G_z$s (Gillingham and Fosdick, 1988) but can be very fatiguing. Acceleration tolerance is usually related to the ability to maintain a sufficient heart level and cerebral arterial blood pressure. Before a gray-out, black-out, and/or G-LOC, retinal and cerebral arterial blood pressure usually fall drastically. During relaxed (no AGSM) G-exposure the cardiovascular response, through arterial and cardiac baroreceptors, increases heart rate and blood pressure within 6-9s in an attempt to counteract the G-induced decrease in blood pressure. Heart level blood pressure is partially restored in 10-15s through this baroreceptor effect (Banks et al. in Fundamentals of Aerospace Medicine 4th ed.). The endurance to withstand repeated G-loads is also related to the ability to maintain an effective respiratory and muscular AGSM. During G-exposures with an AGSM, blood pressure is immediately elevated (1) through muscle contraction of the legs and abdomen, causing peripheral vasoconstriction; and (2) through the respiratory straining maneuver which increases intra-thoracic pressure and heart contractility.

Caffeine is known to stimulate the cardiovascular and central nervous systems through the activation of the sympathetic nervous system (Denaro et al., 1991), but also to cause relaxation of smooth muscles. It influences cardiovascular stress reactivity and potentiates the body's stress response (Lane et al., 1990). In response to caffeine ingestion, blood pressure rate of increase appears to be highest during the first 30 min, with a smaller rise during the next 30 minutes, followed by a weak response after an hour (Onrot et al., 1985).

Caffeine has also been well demonstrated to enhance exercise performance although its ergogenic benefits seem highly dependent upon the duration, intensity, and mode of exercise. In the athletic arenas most closely resembling performance of the AGSM under G-exposure, the literature is inconclusive. For example, Beck et al. (2006) observed that caffeine ingestion enhanced performance of a 1-RM bench press but did not improve performance of a 10-RM bench press or a 10-RM leg extension exercise, nor did it improve performance of repeated 30-s Wingate tests. However, Andersen et al. (2000) observed that short distance (2000 m) rowing performance was improved after ingesting 6 mg caffeine/kg body weight, the improvement being

most apparent within the first 500 m. Myers and Caferelli (2005) determined that ingesting 6 mg caffeine/kg body weight increased time to exhaustion during sub-maximal knee extension.

Caffeine-induced increases in blood pressure and heart rate, along with potential increases in muscular strength and endurance, would theoretically be beneficial for increasing G-tolerance. However, despite the fact that MVIC levels during the SACM runs were significantly higher in the caffeine condition compared to the placebo condition, our study did not show any statistical differences in SACM endurance among the different conditions. SACM endurance was the variable of primary interest for this study as that measure is strongly applicable to the air combat environment. The impact of caffeine on muscular endurance may not have been strong enough to have an effect in our scenario of high-intensity muscular work.

Notably, G-tolerance was significantly higher by +0.9 and +0.7 Gz during the gradual onset runs with the caffeine condition compared to no-caffeine and placebo, respectively. Since the lower body muscles are relaxed during this condition and the breathing muscles are engaged for no more than normal breathing (no AGSM), the improved G-tolerance is not explained by an improved stimulating effect on the voluntary muscles. However, the stimulating effect of caffeine on the cardiovascular system discussed above (Denaro, 1991) could have contributed to the improved G-tolerance during the relaxed gradual onset run. This enhanced cardiovascular response while riding relaxed was mild and was likely overwhelmed/masked by the voluntary increase in muscle tension and intrathoracic pressure exerted while performing the AGSM during the SACM. For probably the same reason, this effect was not seen during the rapid onset runs to + 6 Gz. However, this apparent lack of effect could also be due to the fact that, with rare exceptions, all subjects reached and maintained the near maximum time of 15 s during all three conditions. In other words, the G-level may have been too low and the duration too short to reveal potential benefits from caffeine.

Our results did not show any statistically significant difference in systolic or diastolic blood pressure with caffeine compared to no-caffeine and placebo during either the resting or G-exposure conditions. There was a slight trend to increased systolic blood pressure during the caffeine condition while resting before the centrifuge runs, but it was not statistically significant. Possibly, the increase in blood pressure usually associated with caffeine was not sufficient to have any further effect over the already strong baroreceptor response during increased G or when straining maneuvers were used to increase blood pressure for improved G-tolerance. It is also possible that the lack of significant results was simply a product of the reduced sample size. (Due to technical problems, we were only able to measure blood pressure in 6 subjects in the resting condition and in 4 subjects during the increased G exposures).

Surprisingly, heart rate was not significantly higher with caffeine than with no-caffeine or placebo either at rest or at the different increased G-exposures. An increased heart rate with

caffeine is expected through its activation of the sympathetic nervous system both during rest and during physical activity, but this effect was perhaps overwhelmed by increased sympathetic activity due to a G anticipatory effect before the centrifuge runs or the even stronger sympathetic activity during the hard physical work when straining maneuvers were used at increased G. The number of subjects experiencing peripheral light loss with caffeine did not differ from the number experiencing light loss under the other conditions during either the rapid onset or SACM runs, which is in line with the lack of general effect seen on G-tolerance. However, peripheral light loss was statistically less with placebo compared to no-caffeine for both the rapid onset runs and SACM ($p<0.039$ and $p<0.042$, respectively). We have no logical explanation for this finding.

Caffeine is known to induce and increase the frequency of cardiac arrhythmias (Dobomyer et al., 1983). Since arrhythmias are often seen during exposures to high G-loads in the centrifuge, one could expect that caffeine should increase these arrhythmias at increased G-loads. However, we observed relatively few arrhythmias in this study (only 59 premature ventricular contractions (PVC) and 12 bigeminis during the total of 72 G-exposures). The number of subjects experiencing PVCs was highest with caffeine (75%), compared to 38% with no-caffeine and 50% with placebo, indicating that there was a trend (though not statistically significant) for caffeine to cause more arrhythmias. Importantly, none of the 72 centrifuge exposures had to be stopped due to serious arrhythmias.

Cognitive Performance, Mood States, and Alertness. The relative effects of the three drink conditions on cognitive performance were very similar for the Math Processing and the Continuous Processing Tasks. Overall-mean-reaction-times were consistently faster under the caffeine than under the placebo condition, and midway between for the no-caffeine condition. The lack of any statistically significant changes in performance accuracy indicates that the faster overall-mean-reaction times following acceleration exposure were not accomplished at the cost of making more incorrect responses. The current findings of the enhancing effects of caffeine on cognitive performance add to a large, established data base. Numerous studies have shown the beneficial effects of caffeine on alertness and cognitive and psychomotor performance in both sleep-deprived and, with less consistency, well-rested individuals. Among the extensive reviews of this research are those reported by Lieberman (1992, 2001), Institute of Medicine (2001), Rogers and Dinges (2005), Smith (2002), and Weiss and Laties (1962). McLellan, Bell, Lieberman, & Kamimori (2003) and Caldwell et al. (2009) provide thorough reviews and useful guidance specific to caffeine's application and impact on fatigue resulting from sleep disruption during sustained ground and long-haul, nighttime airborne operations, respectively.

Several previous investigations have employed the POMS to evaluate the impact of caffeine on subjective affect and alertness (Doan, Hickey, Lieberman, & Fischer, 2006; Lieberman, Tharion, Shukitt-Hale, Speckman, & Tulley, 2002; Lieberman, Wurtman, Emde, Roberts, & Coviella,

1987; McLellan et al., 2003). In studies evaluating just the administration of caffeine, especially in sleep-deprived subjects, enhanced or recovered performance is typically accompanied by a decrease in fatigue scores and an increase in vigor scores, compared to the effects of a placebo. We found no differences in any of the POMS factors among the caffeine, no-caffeine, and placebo conditions in our well-rested subjects prior to or after acceleration exposure. The lack of significant differences in the current study between the caffeine and placebo conditions for POMS fatigue and vigor may be due, at least in part, to the subjects having been well-rested and in a positive, can-do state of mind (see below) for all conditions.

Overall-mean-reaction-time on both cognitive tasks was also consistently faster after than before exposure to +Gz acceleration and repeated performance of the anti-G straining maneuver. Physical exercise has been reported to improve cognitive performance. Using a similar pre- versus post-exercise testing procedure as in the present study, Hogervorst, Riedel, and Jeukenrup (1996) found that a one-hour, cycle ergometer endurance test at approximately 70% VO2max improved reaction time performance on both simple and complex cognitive tests. Grego et al. (2004) report electrocortical indices of cognitive function to be enhanced during acute physical exercise. A few studies have evaluated the combined effects of caffeine and exercise on cognitive performance. Hogervorst, Riedel, Kovacs, Brouns, and Jolles (1999) and Hogervorst et al. (2008) reported an additive effect of caffeine on the alerting and performance enhancing effects of exercise. Kruk et al. (2001) reported that, compared to placebo, caffeine ingestion prior to exercise improved choice reaction time performance during exercise to volitional exhaustion on a bicycle ergometer. We did not see an additive effect of caffeine with exercise in this study, as evidenced by a lack of significant drink by acceleration interactions.

As for the impact of performing anti-G straining maneuvers, it was expected that any post-acceleration changes in POMS factors, if any, would be limited to a small increase in fatigue scores and a small decrease in vigor scores compared to pre-acceleration scores,[2] especially considering that the subjects in the current study were physically fit and experienced centrifuge riders. And, indeed, a small but significant increase in fatigue and decrease in vigor occurred from pre- to post-acceleration, accompanied by a similarly small but significant increase in confusion. However, it is important to note that these small but significant pre- to post-acceleration changes, when compared against the backdrop of their respective range of possible scores (refer to Table 3), indicate the subjects to have been in a very positive and alert affective state both before and after acceleration exposure regardless of drink condition. Similarly, both the overall-mean alertness ratings reported before and after acceleration exposure, while nearly showing a significant decrease, represent states of high alertness (Table 3; mean ratings of 1.8 and 2.4, respectively, on a 7-point scale).

[2] While negatively related, the POMS fatigue and vigor states appear to be independent factors and not opposite poles of a single bipolar factor.

CONCLUSIONS

Based on the results of this investigation, we conclude that caffeine ingestion mildly increases relaxed G-tolerance but does not increase the effectiveness of one's AGSM under G. Fighter and trainer pilots who need considerable strength and muscular endurance to effectively perform an AGSM are best served to maintain a rigorous physical training program along with refining their AGSM technique. The results also confirmed previous findings demonstrating the enhancing effects of caffeine and physical exercise on cognitive performance.

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